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REMARKS ON THE INCLUSIVE DECAYS $\Lambda_b \to X_s\gamma$ AND $\Lambda_b \to X_c l\bar{\nu}_l$ *

M. Gremm, G. Köpp, F. Krüger and L. M. Sehgal

Institut für Theoretische Physik (E), RWTH Aachen, D-52074 Aachen, Germany

We consider the effects of quark-binding on the angular distribution and polarization characteristics of the inclusive decays $\Lambda_b \to X_s\gamma$ and $\Lambda_b \to X_c l\bar{\nu}_l$ ($l = e, \tau$), using the methods of heavy quark effective theory.

1 Introduction

This is a summary of two papers[1,2] in which we have considered the effects of quark-binding on the decays $b \to s\gamma$ and $b \to ql\bar{\nu}_l$, when the b-quark is embedded in a polarized Λ_b-baryon.

In the free-quark model (FQM), the decay $\vec{\vec{b}} \to s\gamma$ of a polarized b-quark produces a monochromatic photon whose angular distribution relative to the b-spin direction is

$$\frac{d\Gamma}{d\cos\theta} \sim 1 - \frac{1-\xi}{1+\xi}\cos\theta\ , \tag{1a}$$

where $\xi = m_s^2/m_b^2$. The polarization of the photon is

$$P_\gamma = -\frac{1-\xi}{1+\xi}\ . \tag{1b}$$

Likewise, in the decay $\vec{\vec{b}} \to ql\bar{\nu}_l$ the angular distribution of the lepton relative to the b-spin is

$$\frac{d\Gamma}{d\cos\theta} \sim 1 - \frac{1}{3}\, f\left(\frac{m_q^2}{m_b^2}, \frac{m_l^2}{m_b^2}\right)\cos\theta\ , \tag{2}$$

where $f\left(m_q^2/m_b^2, m_l^2/m_b^2\right)$ is a calculable function equal to unity when m_q and m_l are zero. The lepton in the final state has a characteristic polarization $\vec{P}$, with a longitudinal component P_L and a transverse component $P_T \sim m_l/m_b$ in the decay plane. Our objective is to analyse how the free-quark characteristics (1) and (2) are modified when the b-quark is a constituent of a polarized Λ_b-baryon.

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2 The decay $\Lambda_b \to X_s\gamma$

The decay $\vec{\vec{\Lambda}}_b \to X_s\gamma$ is governed by the effective Hamiltonian

$$H_{\rm eff} = \frac{-4G_F}{\sqrt{2}}\frac{e}{16\pi^2}\, V_{tb}V_{ts}^*\, c_7(m_b) \times \bar{s}\,\sigma^{\mu\nu}\,(m_bP_R + m_sP_L)\,bF_{\mu\nu}\ , \tag{3}$$

which produces a distribution ($y = 2E_\gamma/m_b$)

$$\frac{d\Gamma}{dy\,d\cos\theta} = \frac{\alpha G_F^2 m_b^2}{2^7\pi^5}\,|V_{tb}V_{ts}^*|^2\,|c_7(m_b)|^2\, y\,{\rm Im}\,T(y,\cos\theta)\ , \tag{4}$$

where the function $T(y,\cos\theta)$, calculated to order $1/m_b^2$ in the operator product expansion (OPE), is[1]

$$T(y,\cos\theta) = 2y^2m_b^3\,\frac{1}{(y-y_0-i\epsilon)} \times \{[1+h(y)K]\,(1+\xi) - \cos\theta\,[1+\epsilon_b+h(y)K]\,(1-\xi)\}\ , \tag{5}$$

with

$$h(y) = \frac{5}{3} - \frac{7}{3}\frac{y}{(y-y_0-i\epsilon)} + \frac{2}{3}\frac{y^2}{(y-y_0-i\epsilon)^2}\ . \tag{6}$$

The parameters K and ϵ_b are defined by

$$K = -\langle\Lambda_b|\,\bar{h}_v\frac{(iD)^2}{2m_b^2}h_v\,|\Lambda_b\rangle\ , \tag{7}$$

$$(1+\epsilon_b)s^\mu = \langle\Lambda_b(s)|\,\bar{b}\,\gamma^\mu\gamma^5 b\,|\Lambda_b(s)\rangle\ , \tag{8}$$

and express the effects of quark-binding. The angular distribution of the decay photon is

$$\frac{d\Gamma}{d\cos\theta} \sim 1 - K - (1+\epsilon_b-K)\frac{1-\xi}{1+\xi}\cos\theta\ , \tag{9a}$$

Table 1: Angular distribution of leptons in the inclusive decay $\overset{\Rightarrow}{\Lambda}_b \to X_q l \bar{\nu}_l$, including quark-binding effects.

Decay	$d\Gamma/\cos\theta$ (arbitrary unit)
$\Lambda_b \to X_u e \bar{\nu}_e$	$(1-K) - \frac{1}{3}(1+\epsilon_b - K)\cos\theta$
$\Lambda_b \to X_c e \bar{\nu}_e$	$(1-K) - 0.25(1+\epsilon_b - K)\cos\theta$
$\Lambda_b \to X_u \tau \bar{\nu}_\tau$	$(1-K) - 0.45(1+\epsilon_b - 1.8\,K)\cos\theta$
$\Lambda_b \to X_c \tau \bar{\nu}_\tau$	$(1-K) - 0.34(1+\epsilon_b - 2.7\,K)\cos\theta$

and the photon polarization, as a function of direction, is

$$P_\gamma(\cos\theta) = -\frac{1-\xi-\alpha(1+\xi)\cos\theta}{1+\xi-\alpha(1-\xi)\cos\theta} \ , \qquad (9b)$$

with $\alpha = (1+\epsilon_b - K)/(1-K)$. The results (9a) and (9b), which are the QCD-improvements of the results (1a) and (1b), are represented in Figs. 1 and 2, for $K = 0.01$ and $\epsilon_b = -\frac{2}{3}K$.

3 The decay $\Lambda_b \to X_q l \bar{\nu}_l$

In the case of the decay $\overset{\Rightarrow}{\Lambda}_b \to X_q l \bar{\nu}_l$ ($q = u$ or c, $l = e$ or τ), the differential decay rate has the form $d\Gamma \sim L_{\mu\nu} H^{\mu\nu}$, where the hadronic tensor is

$$H_{\mu\nu} = \frac{1}{\pi} \mathrm{Im}\, i \int d^4x \ e^{-iq\cdot x} \left\langle \Lambda_b \right| \mathrm{T}\left\{ j_\mu^\dagger(x) j_\nu(0) \right\} \left| \Lambda_b \right\rangle \ , \qquad (10)$$

with $j_\mu = V_{qb}\, \bar{q}\gamma_\mu(1-\gamma_5) b$. This tensor may be expanded in terms of 5 structure functions $T_1 \ldots T_5$, for unpolarized Λ_b, and 9 additional functions $S_1 \ldots S_9$, for polarized Λ_b. Using OPE to order $1/m_b^2$, it is possible to determine all of these structure functions in terms of the parameters K and ϵ_b.

The inclusive distribution of the lepton as a function of energy and angle has the form[2] ($y = 2E_l/m_b$)

$$\frac{d\Gamma}{dy\, d\cos\theta} \sim \left[A_0 + A_1 K + \{B_0(1+\epsilon_b) + B_1 K\}\cos\theta\right] \ , \qquad (11)$$

where $A_{0,1}$ and $B_{0,1}$ are calculable functions of y. In the limiting case $\Lambda_b \to X_u e \bar{\nu}_e$, with $m_u = m_e = 0$, the functions A_0, B_0 have a form familiar from μ-decay:

$$A_0 = (3-2y)y^2 \ , \qquad B_0 = (1-2y)y^2 \ . \qquad (12)$$

Table 1 lists the inclusive distribution $d\Gamma/d\cos\theta$, integrated over y, for the various inclusive processes $\overset{\Rightarrow}{\Lambda}_b \to X_q l \bar{\nu}_l$. A further observable of interest is the τ-

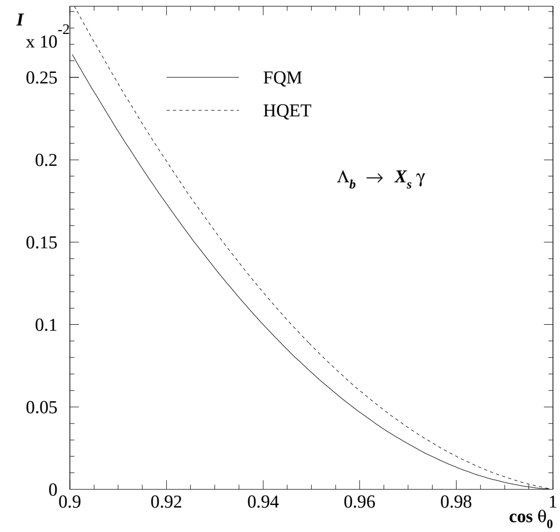

Figure 1: The fractional intensity I of photons in the forward cone $\cos\theta_0 \le \cos\theta \le 1$.

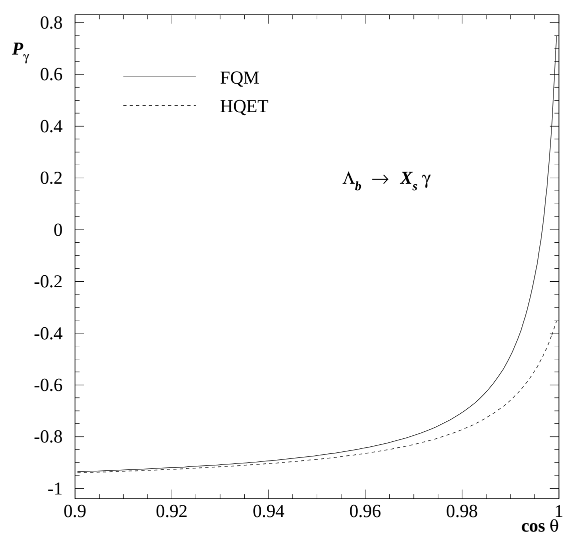

Figure 2: The photon polarization P_γ in the inclusive Λ_b decay as a function of the photon direction with $K = 0.01$ and $\epsilon_b = -\frac{2}{3}K$.

polarization in the decay $\Lambda_b \to X_c \tau \bar{\nu}_\tau$. The τ has a longitudinal polarization component P_L as well as a transverse component P_T in the decay plane. These are shown in Figs. 3 and 4, as functions of the lepton energy. The average values are $\langle P_L \rangle \approx -0.70$ and $\langle P_T \rangle \approx 0.19$. The quark-binding effects are generally small, except in the region of large y, where the OPE breaks down, and a "smoothing" procedure is necessary. When the Λ_b is polarized, there is an interesting correlation of $\vec{s}_\tau$ with $\vec{s}_{\Lambda_b}$. In particular, the τ-lepton can have a small polarization component $P_\perp$ perpendicular to the decay plane, which is proportional to K, and hence a pure manifestation of the "Fermi motion" of the b-quark in the hadron.

References

1. M. Gremm, F. Krüger and L. M. Sehgal, *Phys. Lett.* **B355** (1995) 579, and references therein.
2. M. Gremm, G. Köpp and L. M. Sehgal, *Phys. Rev.* **D52** (1995) 1588, and references therein.

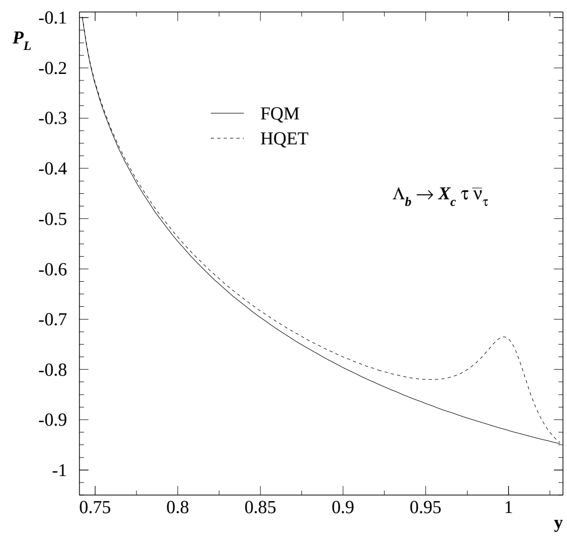

Figure 3: Longitudinal polarization of τ in $\Lambda_b \to X_c \tau \bar{\nu}_\tau$.

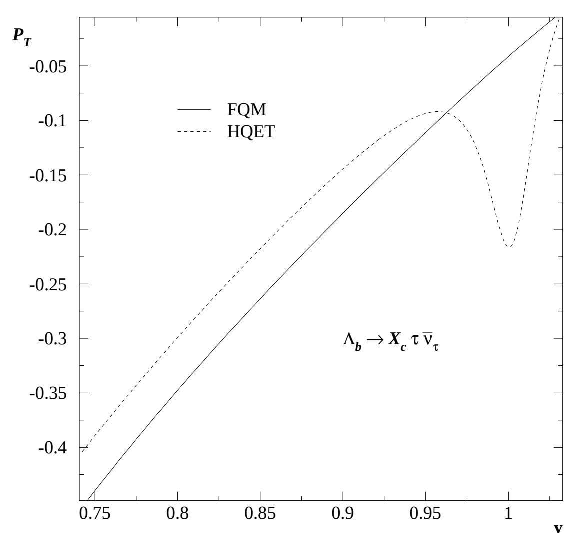

Figure 4: Transverse polarization of τ (in decay plane) in $\Lambda_b \to X_c \tau \bar{\nu}_\tau$.